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September 21, 2000

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APPLICATION NUMBER: *60/152,461*
FILING DATE: *September 03, 1999*

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JC644 U.S. PTO
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PROV

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR A PATENT under 37 CFR 1.53 (b)(2).

Docket Number	14112-3USPR	Type a plus sign (+) inside this box→	+

INVENTOR(s)/APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
Grudin	Oleg		Montreal, Canada
Gendin	Alexander		Montreal, Canada

JC583 U.S. PTO
60/152461
09/03/99

TITLE OF THE INVENTION *(280 characters max)*

Method for flowmeter linearization

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ENCLOSED APPLICATION PARTS *(check all that apply)*

X	Specification	*Number of Pages*	3	X	Small Entity Statement	
X	Drawings	*Number of Sheets*	2		Other (specify)	

METHOD OF PAYMENT *(check one)*

	A check or money order is enclosed to cover the Provisional filing fees	PROVISIONAL FILING FEE AMOUNT ($)	
X	The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 19-5113		$75.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No

[ ] Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE J. Anglehart

Date Sept. 2, 1999

TYPED or PRINTED NAME James Anglehart

REGISTRATION NO. *(if appropriate)* 38,796

[ ] Additional inventors are being named on separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

In th United States Patent and Trademark Office

"Express Mail" mailing label number: EH576252816US
Date of Deposit: September 3, 1999

I hereby certify that the attached U.S. Patent Application, informal drawings, transmittal letter, verified statement, declaration and power of attorney, information disclosure statement, and application fee are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner of Patents, Washington, D.C. 20231.

Randall L. Reed

Randall L. Reed
(Signature)

September 3, 1999

Assistant Commissioner of Patents
Box: Provisional Patent Application
Washington, D.C. 20231

Dear Sir:

Transmitted herewith for filing is the Provisional Patent Application of:

Inventor: Grudin, Oleg and Gendin, Alexander
For: Method for Flowmeter Linearization
Attorney Docket Number: 14112-3USPR

Enclosed are:

1. A Specification with 3 pages.

2. 2 sheets of informal drawings.

3. A Provisional Application for Patent Cover Sheet, signed on September 2, 1999 by James Angelhart Reg. # 38,796. (1 page)

4. A Declaration for Small Entity Status Sheet, signed by Oleg Grudin and Alexander Gendin on September 2,1999. (1 page)

5. A return receipt post card.

Respectfully submitted,

Date: September 3, 1999

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METHOD FOR FLOWMETER LINEARIZATION.

Background

Typically, flowmeters contain two key functional parts – Gas Flow Receiver (GFR) and differential pressure transducer. The GFR is a tube through which the gas flow to be measured is conducted. The differential pressure generated by a flow resistive element inside the GFR is measured by a differential pressure transducer. Some practical applications, such as spirometry, require that the GFR have an extremely simple shape. This requirement results from the necessity to simplify the GFR cleaning or sterilization, or even the necessity to use cheap disposable GFRs. Analogous requirements may occur in many technical applications where the measured gas flow can be contaminated by liquid or solid particles or water vapor, which may adversely affect the conversion factor of the GFR, and necessitate periodic cleaning of the GFR. This may be relevant in many industrial systems, for example gas handling systems, and gas pipelines.

It was shown that the GFRs with simple shape and non-linear conversion characteristic [(flow)-(differential pressure)] have serious advantages with respect to traditional linear Fleisch- or Lilly-type tubes [US Patent 5038773]. However, the differential pressure which is generated by this type of GFR is a square function of the flow, which results in the following problems.

A requirement to measure flow in a dynamic range of 10^3, say from 15ml/s to 15l/s (spirometry), necessitates the measurement of differential pressure, generated by the GFR, in a dynamic range of $10^6=(10^3)^2$. On the other hand, a limitation of maximal flow impedance of the GFR at about 150Pa·s/l, established by contemporary spirometry standards (American Thoracic Society Standards for Spirometry), restricts the maximal generated back-pressure to (150Pa·s/l)x(15l/s)≈2kPa. Therefore the minimum detectable differential pressure of the pressure transducer should be at the level of several mPa. This requirement, combined with the necessity to operate in a dynamic range of six orders of magnitude, is a serious challenge for differential pressure transducers. Medical Graphics Corp. proposed a flowmeter containing two differential pressure sensors with an overlapping operating range of six orders of magnitude having a special sensor activated at low flows [US Patent 5038773]. The electronic module of this spirometer has a sophisticated structure and contains sub-modules providing analog signal conversion before being digitized by an analog-to-digital converter (ADC). The analog signal conversion includes absolute value and square root functions of the analog voltage, and selectable gain amplification. In other words, linearization of the flowmeter is performed at the level of hardware, by complex conversion of an analog signal. These operations should be made with high accuracy, to preserve the performance of the flowmeter. As a result, the flowmeter includes quite complex electronics, which may restrict its usage for certain applications.

Usage of thermoanemometer-type sensors connected in parallel to the GFR for flow measurements has been reported earlier [U.Bonne, K.Fritsch Mikroanemometer für die Durchflubmessung von Gasen, Technisches Messen, 1994, v.61, n.7, pp.285-294; T.R.Ohnstein, R.G.Johnson, R.E.Higashi, D.W.Burns, J.O.Holmen, E.A.Satren, G.M.Johnson R.E.Bicking, S.D.Johnson Environmentally Rugged, Wide Dynamic Range Microstructure Airflow Sensor, Proceedings on Solid-State Sensors and Actuators Conference (1990), pp.158-160]. Having a linear operating range of about four orders of magnitude and total operating range of more then six orders of magnitude [Frolov G.A., Gendin A.V., Grudin O.M., Katsan I.I., Krivoblotskiy S.N., Lupina B.I. Micromechanical thermal sensors for gas parameters measurements. Proceedings of 1996 ASME International Engineering Congress

and Exposition, DSC-Vol.59, Micro-electro-mechanical systems, pp. 61-65], one thermoanemometer-type sensor covers the whole operating range that makes it attractive for usage in flowmeters. Another advantage of thermoanemometer-type sensors is that their resolution can be improved up to several mPa without degrading their dynamic properties. For example, the response time of the mass flow AWM-series sensors manufactured by Honeywell Inc., with resolution mentioned above is about 3ms. An important characteristic of thermoanemometer-type sensors is their nonlinearity at high-amplitude input signals. Therefore a flowmeter containing two nonlinear functional elements, such as the GFR and thermoanemometer-type sensor, has a complex and essentially nonlinear conversion characteristic from flow to output voltage, which must be linearized.

To linearize the flowmeter, its calibration curve *F(V)*, which specifies the correspondence between the flow *F* and the measured voltage *V* must be defined. In practice, in a calibration process, the voltage *V* is measured at several known flows, and the function *F(V)* is calculated with the use of an algorithm to give an accurate fitting of the calculated flow to its real value. Then the calibration curve can be stored in the form of a digitized file, or as an analytical function.

The present invention addresses linearization of an essentially nonlinear flowmeter, containing a GFR with flow-resistive element generating differential pressure close to the square of the flow. The invented linearization method is performed in software, by special processing of the digitized output signal of the flowmeter. This allows significant simplification of the electronics of the flowmeter by elimination of sub-modules performing analog signal conversion functions.

Summary of the invention and description of the drawings

1. The general type of the calibration function, *F(V)*, of the flowmeter containing flow resistive element generating differential pressure close to the square of flow, is invented:

$$F(V) = \sum_{i=1}^{N} A_i V^{\frac{1}{\alpha_i}}$$

where N is equal or greater than 3; parameters $\alpha_i > 1$ (preferable values of α_i are close to 2); and A_i are coefficients determined experimentally for a particular flowmeter, to give the best linearization results.

2. For higher accuracy, the whole operating range of the flowmeter is divided into several (at least two) sub-ranges and a calibration curve is found separately for each of the sub-ranges as specified in 1).

Fig. 1 shows the calibration curve of the flowmeter.

Fig. 2 shows deviations of the volumes measured by the flowmeter from the actual volume of the calibrated syringe.

Description of the preferred embodiment

For the verification of the invented linearization method, a typical flowmeter was used. The flow meter contained the GFR, the tube 120mm long with input inner diameter of 21mm and inner diameter of 19mm at the center of the tube. A planar star-like diaphragm with six beams each having 1mm width, and with a central spot having diameter 4mm, was used as a flow-resistive element. This diaphragm with thickness of 1mm was located at the center of the tube, and generated differential

pressure close to the square of the flow. Mass flow sensor AWM2200 (Honeywell) was connected to the GFR with two plastic hoses to measure flow-induced differential pressure.

The operating flow range of the flowmeter was divided into two sub-ranges, 0 – 2 l/s and 2 – 15 l/s. Coefficients A_i of the calibration curve specified in 1) were found for the function with N=5 and α_i=2. The functions defined for the two sub-ranges are graphed in Fig. 1. After calibration, the calibration curve was stored in a computer file.

For checking of the flowmeter accuracy, its GFR was connected to the 3-liter calibration syringe "SpiroCal" fabricated by Burdick Inc. (Milton, WI, USA). Then, air was pumped in and out of the syringe with different flow rates by piston strokes. The expired and inspired air volumes were measured by the flowmeter and compared with the actual volume of the syringe. Deviations of these two volumes (in %) shown in Fig. 2, do not exceed 2%. This confirms that the accuracy of the flowmeter, is within 2% or better, exceeding the requirements specified by the ATS standards for spirometry.

In practice, the choice of the parameters N and α_i may differ from those used in the presented example depending on the applications. For example, the linearization procedure with N=6 was also successfully tested, although the algorithm of finding of coefficients A_i was more complicated.

Parameters α_i can be chosen so as to give better fitting of the calculated calibration curve with actual flow response of the flowmeter. At low flows, the dominant contribution is given by the first element of the sum: $F(V) \approx A_1 V^{\frac{1}{\alpha_1}}$. Transforming this equation, one obtains $V \approx bF^{\alpha_1}$. In this case, the parameter α_1 defines conversion from flow to output voltage at low flows, which mainly depends on the construction of the GFR. Usually, the GFR with diaphragm-type flow-resistive elements generates differential pressure which varies near to the square of flow. For these types of GFRs, α_1=2 gives a reasonable approximation of the calibration curve. Nevertheless some deviations of the parameter α_1 as well as parameters α_i ($1<i<N$) from the value of 2 are also possible in the invented linearization method.

Depending on the accuracy requirements and flow operating range, the number of sub-ranges may also vary from one to some number greater than two. This choice depends on the particular application.

Applicant or Patentee: Oleg Grudin and Alexander Gendin
Application or Patent No.: ________________ Atty. Dkt. No.: 14112-3 USPR
Filed or Issued: herewith
Title: "Method for flowmeter linearization"

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS [(37 CFR 1.9(f) and 1.27 (b)] - INDEPENDENT INVENTOR

As a below named inventor, I hereby declare that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- ☒ the specification filed herewith with title as listed above.
- ☐ the application identified above.
- ☐ the patent identified above.

I have not assigned, granted, conveyed or licensed and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- ☒ No such person, concern, or organization exists.
- ☐ Each such person, concern, or organization is listed below.

FULL NAME ________________
ADDRESS ________________
( ) INDIVIDUAL ( ) SMALL BUSINESS CONCERN ( ) NONPROFIT ORGANIZATION

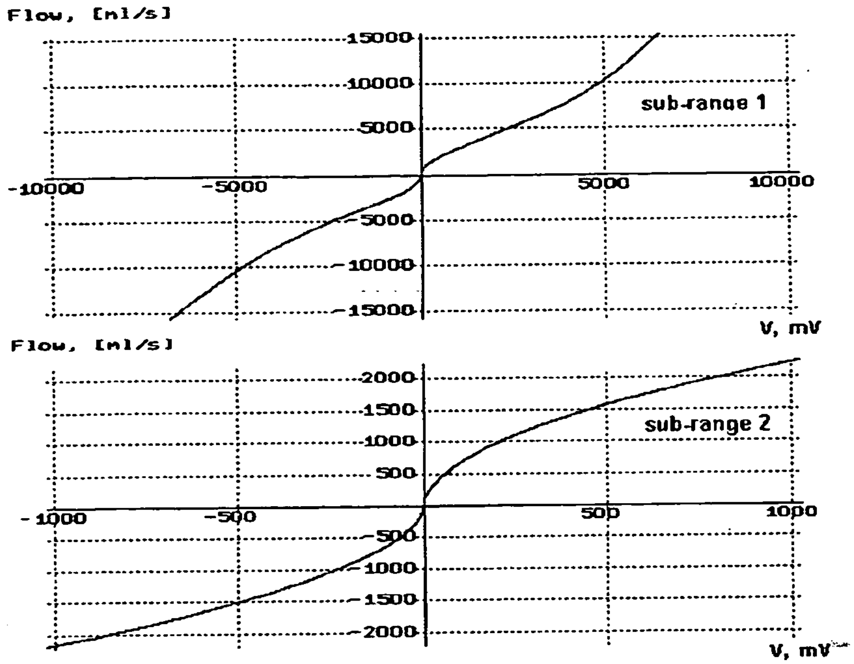
FULL NAME ________________
ADDRESS ________________
( ) INDIVIDUAL ( ) SMALL BUSINESS CONCERN ( ) NONPROFIT ORGANIZATION

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. [37 CFR 1.27]

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. [37 CFR 1.28(b)]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF INVENTOR	SIGNATURE OF INVENTOR	DATE
Oleg Grudin	[signature]	02 Sept 1999
Alexander Gendin	[signature]	2 Sept. 1999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sub-range 2
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Fig.1.

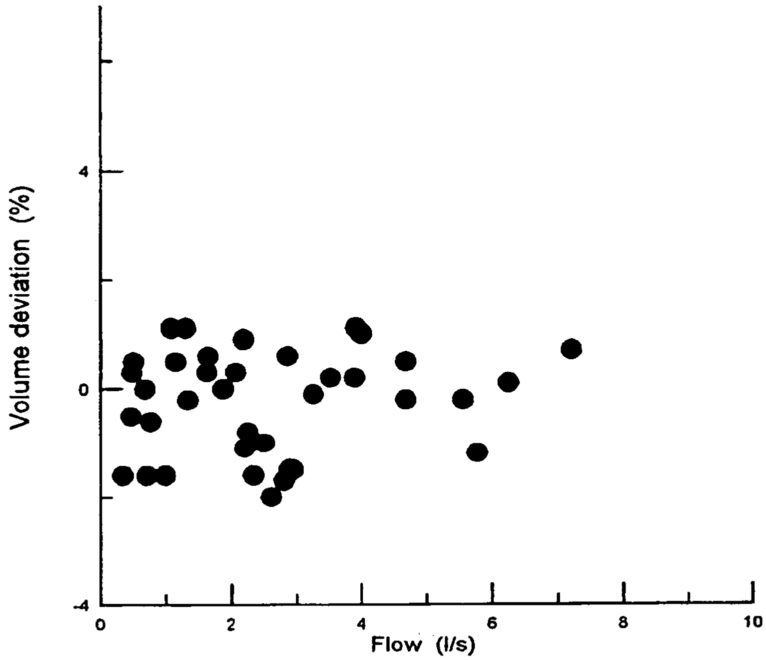

Fig. 2.